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REVIEW ARTICLE

Innovations in the food packaging market: active packaging

Joanna Wyrwa[1] · **Anetta Barska**[1]

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Abstract The requirements towards packaging and articles intended to come into contact with food are systematically growing. Due to the growing consumer interest in consumption of fresh products with extended shelf life and controlled quality, manufacturers have to provide modern and safe packaging. It is a challenge for the food packaging industry and also acts as a driving force for the development of new and improved concepts of technology packaging. It is in order to meet these needs that active packaging can be applied. This article presents a new generation of packaging, which allows to maintain and even improve the quality of the packaged product, which is an essential advantage particularly in the food industry. It is to this end that the role and the application of active packaging were discussed. Among the solutions belonging to the active packaging, there are oxygen and moisture scavengers, ethylene regulators, and antimicrobial packaging. Active packaging is an excellent solution for a wide range of applications in the food industry. The most important advantage resulting from their use is reduction in loss of food products due to extension of their shelf life. Active systems are the future direction for development of food packaging and their commercial success should be expected in the coming years. It will undoubtedly result from constantly improved technologies of their production and the knowledge about mechanisms of their functioning and the effectiveness of their operation in ensuring food safety accumulated by both producers and consumers over time.

Keywords Active packaging · Innovations · Food packaging market

✉ Joanna Wyrwa
j.wyrwa@wez.uz.zgora.pl

Anetta Barska
a.barska@wez.uz.zgora.pl

[1] Faculty of Economics and Management, University of Zielona Góra, ul. Podgórna 50, 65-246 Zielona Góra, Poland

Introduction

Currently, packaging is an essential element in modern trade in goods, which guarantees preserving the quality of food products. It also plays a key role by protecting packed products against external conditions, affecting the quality and health safety of food products, making transportation, storage, and dispensing of products more easy. The dynamic growth of importance of packaging contributes to the continuous improvement of production methods and ways.

Packaging production is a global industry, which is characterized by its internal diversity and each of its sectors individually affects the situation on the market. The requirements towards packaging and articles intended to come into contact with food are systematically growing. Due to the growing consumer interest in consumption of fresh products with extended shelf life and controlled quality, manufacturers have to provide modern and safe packaging. It is a challenge for the food packaging industry and also acts as a driving force for the development of new and improved concepts of technology packaging [1, 2]. Therefore, packaging producers are looking for solutions that allow to improve such properties of packaging materials as: an adequate barrier to gases, UV protection, extension of the storage period, transparency, and environmental performance [3].

Due to its expansiveness in creating new products, the food industry has created completely new demands on the packaging market.

Modern packaging extends the shelf life of food products and better techniques for storage and refrigeration chains enable longer transportation [4]. Packaging of the new generation affects a product and thus controls its quality. It is in the literature that there are various terms used to describe new technologies of packing: active, smart, interactive, and intelligent.

As a result of the implementation of the “Actipak” project, the definitions were systematized and new packaging systems have been placed on the market together with the relevant regulations [5]. Active packaging, which is used to protect the quality of the packed products through modern systems, was differentiated from intelligent packaging which generally complements active packaging and its role is to communicate with a buyer.

Farmer [6] defines active packaging as “the one, which not only passively contain and protect food, but also perform other actions while smart packaging or intelligent packaging traces and informs”. It is an extension of the traditional packaging functions such as providing protection, comfort of use, and longer shelf life and storage periods. He also emphasizes that “packing of the future will not only be a barrier but it will also interact with packaged products” [7].

This article presents a new generation of packaging, which allows to maintain and even improve the quality of the packaged product, which is an essential advantage particularly in the food industry. The aim of the study is to systematize the knowledge and identify the research trends concerning the active packaging o food products. It is to this end that the role and the application of active packaging were discussed. Among the solutions belonging to the active packaging, there are oxygen and moisture scavengers, ethylene regulators, and antimicrobial packaging. The article has the characteristics of a review, whereas the main research method applied is literature query. The article presents the current state of the scientific discussion on the principles and mechanisms of active packaging, indicating the process of dynamic improvement of production technology of this innovative packaging solution.

According to forecasts of experts, the emerging generations of active packaging are the future of food packaging [7–15]. It is estimated that the share of the so-called advanced packaging represents approximately 5% of the total value of the packaging market, of which 35% belongs to active systems. Although the active packaging has a small share in the value of the sales of all packaging, but there are indications for a rapid growth of their sales in subsequent years. The interest in these solutions is reflected in the number of patent applications and granted patents [8]. These types of solutions were introduced in Japan and in the USA first, and now, they can be seen in Europe. Probably, the later introduction of these systems on the European market results from existing legal regulations, which were much more restrictive in Europe [1, 16]. Intensification of interest in active and intelligent packaging in Europe is also reflected in the growing number of research projects relating to their development [12].

Active packaging system

Active packaging is a solution, in which the packaging, the product, and the environment interact. These are the systems, which (as a result of the chemical, physical, and biological activities) actively change conditions of the packed food, cause an extension of its sustainability and thus its shelf life, and guarantee or significantly improve the microbiological safety and/or sensory properties, while maintaining its quality [17, 18].

In contrast to the traditional packaging materials, active packaging causes extending the shelf life of food and preserving its higher quality during reactions with the internal atmosphere and the product [19–22].

Therefore, active packaging systems should be considered an innovative way in the field of food packaging [23, 24]. They interact with the packed product, change the conditions of the packed food, and control its quality at the same time.

Active packaging represents a large and diverse group in terms of both its purpose and solutions applied. The use of proper active packing extends the shelf life of products through its impact on processes emerging in food [25]:

- physiological processes, e.g., breathing of fresh fruit and vegetables;
- chemical processes, e.g., oxidation of fats;
- physical processes in the case of bread staling;
- microbiological changes due to the impact of microorganisms;
- infections caused by insects.

The atmosphere inside packaging can be actively controlled by substances which absorb (scavengers) or release (emitters) gases or steam.

Scavengers are designed to remove undesired components from the environment inside packaging. There is no direct migration between a scavenger and a product but only improvement of the conditions inside packaging, which prolongs a shelf life of the product. Depending on the application, it may be associated with the absorption of oxygen, moisture, ethylene, or carbon dioxide. It is in order to achieve specific effects that such substances as zeolite, cellulose, activated carbon, silica gel, iron ions, ascorbic acid, potassium permanganate, and calcium hydroxide are applied [26].

The second group of packaging consists of emitters [26]. The principle of operation of emitters is based on releasing desired substances that have a positive impact on food into the packaging environment. Such packaging contains and produces compounds capable to get inside the packaging and inhibit adverse processes. They are intended to guarantee stable conditions during storage and should ensure extension of the shelf life. It is by means of emitters that humidity inside packaging (vegetable packaging) can be controlled, the growth of harmful microorganisms (emitters of CO_2, SO_2, and ethanol) can be inhibited, and bacterial spoilage can be prevented (antibacterials) [25]. Emitters can be fragrant substances, food additives, food ingredients, humidity regulators, and biological active substances, which prevent growth of microorganisms. The most commonly used antimicrobial substances are ethanol, sulfur dioxide, and carbon dioxide [26].

The following active packaging systems are used in the food industry:

- oxygen, carbon dioxide, and ethylene scavengers;
- carbon dioxide emitters;
- odor emitters and absorbers;
- relative humidity regulators (water content in the packaging atmosphere);
- antibacterial substances;
- antioxidants.

It is Table 1 that the selected modern solutions for active packaging taking into account their potential functions in the food retail trade are presented.

To guarantee sustainability of food packaged with the use of innovative technologies, it is highly desirable to maintain the least amount of gas in the free space of packaging. It is in order to ensure a long-term storage and freshness that minimization of the oxygen presence is essential, which may react with the content of packaging [14]. Through the use of oxygen scavengers, it is possible to control residual oxygen inside packaging, which prevents further deterioration of the quality of the packed products [42, 43]. Scavengers remove oxygen from the atmosphere, in which the product is kept, and/or absorb oxygen diffusing through the packaging material during storage. Easily oxidizable compounds (powdered iron, ascorbic acid, unsaturated fatty acids, and unsaturated hydrocarbons), enzymes (glucose oxidase and alcohol oxidase) or photosensitive dyes are used as oxygen scavengers [18]. Their application may be very useful, especially if vacuum packaging (VP) or packaging in modified atmosphere (MPA) is not possible or proves not to be effective.

The response of the most popular oxygen scavengers is based on oxidation of iron compounds [6]. The substances absorbing oxygen based on iron compounds are placed in sachets permeable to oxygen most often. The largest sachets absorbing oxygen available in the market contain approximately 7 g of ferric oxides. Due to the high sorption capacity of iron compounds, the oxygen scavengers based on them are the most effective absorbers in the market. Depending on size of a sachet, the iron compounds can absorb from 20 to 2000 cm^3 of oxygen. Attempts are being made to embed iron compounds absorbing oxygen in different types of polymers, so that the materials obtained in this way may be in the form of labels glued inside packaging, seals of bottle caps, or be an integral part of packaging. In addition, introduction of iron compounds to a polymer matrix ensures that they do not have direct contact with packed food product, which guarantees safety of a consumer. These are oxygen scavengers, in which the substance absorbing oxygen is ascorbic acid and/or its derivatives that are equally popular besides absorbers based on iron compounds. The action of ascorbic acid may be supported by alkaline compounds, salts of aluminum and iron, as well as siliceous iron [44].

The first iron absorber, called Ageless®, was brought to Japanese market by Mitsubishi Gas Chemical Company at the end of the seventies of the last century. Absorbers of this type are currently produced also by other companies under different names, e.g., FreshPax™, FreshMax™ produced by Multisorb Technologies Inc. [8]. It is in these absorbers that zeolites are covered with iron oxide (II) with addition of sodium chloride. Under the influence of oxygen and moisture present in packaged products, iron oxide (II) is oxidized to iron oxide (III). Newer, more efficient iron oxygen scavengers are based on metallic iron obtained as a result of electrolytic reduction [44].

Oxygen scavengers using iron nanoparticles, which react with oxygen even in a moisture-free environment, are a novelty among absorbents based on iron.

It is in food industry that ethylene and carbon dioxide absorbers are used beside oxygen scavengers.

The ethylene level control during food storage plays a key role in extending its shelf life. Ethylene is a phytohormone, which initiates and accelerates ripping processes, causes degradation of chlorophyll, and inevitably leads to a deterioration of the visual and organoleptic quality if fresh or minimally processed fruit and vegetables. Ethylene absorbers are supposed to protect fruit and vegetables sensitive to the hormone [14]. The most commonly used ethylene absorber is potassium permanganate embedded in silica gel [8]. Potassium permanganate changes color after ethylene oxidation from purple to brown. Silica gel with an absorber is packaged in sealed sachets permeable to ethylene, excluding the possibility of contact with the product

Table 1 Selected applications of active packaging in the food industry

Type	Form	Function	Applications	Commercial Product
Oxygen scavengers	Sachets, labels, film, bottle crowns, masterbatch, container suitable for high temperature, film suitable for high temperature	Minimise the effects of oxygen permeation through the packaging material during product shelf life, preserve food product quality, inhibition of unsuitable oxidation (unstable pigments) and aerobic microorganism growth, prevent oxidative rancidity, controlling enzymatic discoloration, inhibition of oxidation of lipids, development of molds, preventing discoloration	High-, intermediate-, and low-moisture foods, foods containing lipids, refrigerated and frozen storage foods, microwaveable food products, reduce microbial growth and nutritional loss, improve product quality and shelf life, prevent discoloration and flavour change, bread, cakes, biscuits, cooked rice, pizza, pasta, cheese, cured meats, fish, coffee, snack foods, dried foods, dried beef, dried fruits, oils, fats, beverages	ActiTUF™ Ageless® ATCO® Bioka Celox™ Cryovac® OS2000 Enzyme-based FreshMax® FreshPax® OMAC® OxyGuard® OxyCatch® OxyRx® Shelfplus® O_2
Carbon dioxide emitters	CO_2 emitter pad, CO_2 emitter and antimicrobial pad, box system with CO_2 emitter	Decrease microorganism growth and spoilage, reduce the metabolic rate of microbes, preserve food quality, preventing swelling of packaging	Reduce respiration rate, increase shelf life of product, inhibit microbial growth, absorbed by moisture or fat roasted ground coffee, snack foods, nuts, bakery products, dried meat, fresh meats, fish products	CO_2® Fresh Pads UltraZap® Xtenda Pak pads SUPERFRESH
Ethylene scavengers	Sachets, film	Reduce ripening and deterioration, extend shelf life, control of ripening of fruits and vegetables	Control concentration of ethylene, improve quality of food fruits, vegetables and other horticultural products	Bio-fresh Ethylene Control Power Pellet Ethysorb EvertFresh Green Bags® Retarder® PEAKfresh® Profresh Ethylene
Flavour/odor emitters and absorbers	Film	Odor stabilization	Absorption of unpleasant odors, emission of odors fruit juices, fried snack foods, fish, cereals, poultry, dairy products, fruit	Anico™ BMH™ Compel Aroma® Aroma-Can®
Moisture scavengers	Sachets, absorbent pads, absorbent tray, dual-compartment system, microwavable film	Control of excessmoisture in food packages, humidity control	Maintain food quality, extend shelf life, reduce microbial growth and degradation of texture, flavour and color fish, meats, poultry, snack foods, cereals, dried foods, sandwiches, fruit, vegetables	Dri-Loc® MoistCatch MeatGuard Linpac Fresh-R-Pax® TenderPac® Nor®Absorbit

Table 1 (continued)

Type	Form	Function	Applications	Commercial Product
Antimicrobial packaging	Antibacterial and antifungal sheets, labels and films, silver-based masterbatch, silver-based trays and films, interleavers, antifungal coating	Inhibition of microorganism growth, extend shelf life, reduce post-harvest decay, maintain storage quality	Fresh fruits and vegetables, meat products, cheese, bakery products, maintain food quality, inhibit microorganisms	Biomaster® AgIon® Irgaguard® Surfacine® IonPure® d2p® Bactiblock® Biomaster® Food-touch® Sanic Films SANICO® Wasaouro®
Antioxidants	Film coating	Inhibition of oxidation processes	Cereal products	ATOX

Source: study based on: [10, 11, 14, 27–41]

in packaging. Another system for elimination of ethylene is impregnation of zeolite clay with an ethylene absorber with suitable additives to enable absorption of other aromatic hydrocarbons. Zeolite clay with an ethylene absorber can be embedded in a packaging film increasing emission of ethylene and carbon dioxide into the outside atmosphere. A disadvantage of this solution is reduction of the transparency of the packaging. A very efficient ethylene absorbent is activated carbon with palladium chloride as a catalyst. This absorbent significantly reduces softening of minimally processed bananas and kiwi fruit as well as counteracts chlorophyll degradation in spinach [45].

Commercial ethylene absorbing systems are sold in the form of separate or integrated with packaging elements. There are following solutions: the Bio-fresh packaging system, the Ethylene Control Power Pellet sachet, Ethysorb, EvertFresh Green Bags®, Retarder®, PEAKfresh®, and Profresh. Systems using potassium permanganate, i.e., Ethylene Control Power Pellet and Retarder®, are in the form of sachets or they are embedded in a polymeric material as finely powdered minerals. In the case of PEAKfresh® and EvertFresh, ethylene absorption is achieved using zeolites located in a polymeric material [17].

To preserve stability of food products, it is necessary to use systems for absorption and emission of carbon dioxide in active packaging. CO_2 is usually eliminated by placing calcium hydroxide or calcium oxide embedded in silica gel in suitable porous sachets inside packaging [45].

A very important group of active packaging consists of active emitters [26]. Such packaging contains and produces compounds capable to get inside the packaging and inhibit adverse processes. They are intended to guarantee stable conditions during storage and should ensure extension of the shelf life. It is by means of emitters that humidity inside packaging (vegetable packaging) can be controlled, growth of harmful microorganisms (emitters of CO_2, SO_2, and ethanol) can be inhibited, and bacterial spoilage can be prevented.

It is in the case of these systems that much attention should be paid to safety and migration of compounds to food [5].

These are the systems emitting carbon dioxide that deserve more attention due to their beneficial antimicrobial effects. This gas penetrates most packaging materials much faster and should be systematically replenished to ensure its appropriate level (min. 20%).

Carbon dioxide emitters are often used with oxygen scavengers. In such systems, the oxygen absorbed by an oxygen scavenger is directly replaced with carbon dioxide. It is in practice that bifunctional sachets are used for this purpose (labels and mats), which contain a CO_2 emitter and an oxygen scavenger, which absorb oxygen and produce the same volume of carbon dioxide. Iron carbonate

(II) and metal halide as a catalyst are used usually in them. An available solution of this type is the product called CO_2® FreshPads, which is proposed as an active element for packing meat, poultry, and seafood. The liquids secreted from food are absorbed by mats and react with citric acid and sodium bicarbonate. This reaction produces carbon dioxide. A similar solution has been presented by the Codimer SARL company (France). It consists of a standard perforated tray, under which there is a porous sachet containing sodium bicarbonate and sodium ascorbate [8].

The largest group of emitters consists of antimicrobial substances for use inside packaging. These substances may be added to packaging in different forms such as [5]:

- sachets or mats with volatile antimicrobial compounds;
- active substances embedded in the polymer structure;
- active substances applied to the polymer surface;
- active substances immobilized on the polymer using ionic and covalent bonds;
- packaging films, which have antimicrobial properties (e.g., films based on chitosan);
- edible food coatings.

Emitters of smell and taste are also an interesting solution. Sensory changes in food products may result from intentional or unintended reactions between the product and the packaging material and also because of inappropriate material properties important for protecting product quality.

Emitters of smell distribute scent masking fragrant substances in packaging. Besides, the emitted fragrant substances may enhance natural aromas of packaged product, as in the case of fruit and thereby encourage consumers to purchase. Smell emitters are usually substances, which can be used as additives to plastics, including polyethylene and polypropylene, polyamide, polyester, and polyvinyl chloride. These substances are characterized by high thermal resistance [25].

To guarantee high quality of food, it is important to control humidity in packaging. Moisture scavengers are an effective tool for monitoring water content in food packaging. The presence of too much water in a packed product causes larger microbiological contamination and shortens product shelf life at the same time, which may also result in resignation from purchasing. The main task of the humidity control is to reduce the biological activity of water and inhibit growth of bacteria, molds and yeasts.

Market applications of humidity controllers are divided into two categories [17]:

- Liquid absorbers (inserts, sheets) containing two or more layers are made from synthetic polymers, in the structure of which there are hygroscopic substances, which are supposed to absorb liquid from meat and/or fish; their aim is to give packed food products favorable sensory characteristics and prevent development of microorganisms.
- Relative humidity regulators (sachets or labels) containing dewatering agents; they are used to control humidity for many types of products including cheese, meat, nuts, and spices.

The simplest moisture scavengers are sachets filled with absorbing materials such as: silica gel, zeolites, cellulose fibers, or sodium chloride. Sachets of the Dow Chemical Company made of Tyvek®, characterized by a very high vapor permeability, are an example of such a solution. These sachets enable to keep a certain humidity level in packaging which hinders development of mold but does not solve the problem of water loss in the packed product [44]. The so-called wrappings of the Japanese Chefkin company are much more technically advanced and enable to control relative humidity in packaging. They consist of two layers. The external layer is impermeable to water vapor, while the internal layer is permeable to water vapor; however, it does not allow liquid water to get out. In the space between the layers, there is a glucose solution. At high humidity inside the packaging, the water contained in the food product penetrates the internal layer and is absorbed by the glucose solution. On the other hand, when the humidity is low, the water vapor from the glucose solution gets inside the packaging. The concentration of the glucose solution determines the level of the relative humidity, at which the migration of water appears [8]. The Japanese Showa Denko Company has presented a similar solution in the form of a "sandwich-like" wrapping composed of the layers made from polyvinyl alcohol, between which there is propylene glycol [25], whereas the Dai Nippon Company offers a moisture absorber in the form of a multilayer material made from paper, sodium polyacrylate, charcoal, and ethylene copolymer with vinyl acetate [44].

It is in the field of active packaging that different types of antibacterial packaging are also applied (antimicrobial packaging). The mechanism of their action is based on migration of compounds having the ability to inhibit the development of microorganisms on the surface of and then inside a product. As a result of migration of active antimicrobial substances, the lag phase is extended and the speed of microorganisms' growth is reduced [8]. Packaging showing the ability to inhibit growth and development of microorganisms or destroy them directly is used to limit the development of undesirable microflora by adding an antimicrobial component or using a polymer showing such properties [20]. It makes it possible to extend shelf life of a product and ensures maintenance of its appropriate microbiological condition for a longer time.

The antimicrobial agents may be added to packaging in different forms such as [5]:

- sachets or mats with volatile antimicrobial compounds;
- active substances embedded in the polymer structure;
- active substances applied to the polymer surface;
- active substances immobilized on the polymer using ionic and covalent bonds;
- packaging films, which have antimicrobial properties (e.g. films based on chitosan);
- edible food coatings.

Sachets and insertions containing substances showing antimicrobial properties are the most commonly used form of antimicrobial packaging. The chemical compounds in the sachets get out from the sachets to the surface of the packed product or into the atmosphere inside packaging and prevent the growth of bacteria and other microorganisms. Another type of an antimicrobial packaging is based on solutions, in which an active component is inside a packaging material. Antimicrobial substances are introduced during production processes of plastic films, e.g., as a result of embossing. Antimicrobial packaging may also be produced with the use of components showing natural antimicrobial activity, e.g. enzymes, bacteriocins, and be activated as a result of chemical or physical modifications [8].

There have been numerous studies on antimicrobial packaging intended for food carried out in the recent years. New types of plastics and antimicrobial substances have been used. Most of these solutions enable to control growth of microorganisms and effectively extend shelf life of food products. However, the market offer of such products is still too poor. Most likely, it is due to the restrictive legislation and sanitary regulations in individual countries as well as little consumer acceptance for such solutions at relatively high cost of their use [46].

The commercially available antimicrobial packaging systems are based primarily on substances containing silver. One of the first inorganic compounds, which is based on silver, is Zeomic®. This material has been produced by Sinanen Zeomic since 1984. It allows to control growth of Gram-positive and Gram-negative bacteria as well as development of fungi. Moreover, compared to organic of antimicrobial substances, it shows good resistance to high temperature. Other substances with silver in zeolite work in a similar way: Microban®, AgIon®, and Irgaguard® [8, 17].

Active packaging and traditional packaging

Technological advancement and increasing competition have resulted in the need to modernize and improve the quality of packaging introduced on the market. New trends in this field aim to increase the functionality of packaging. The expectations toward packaging and products intended to come into contact with food are steadily increasing. The development of new technologies related to materials and products intended to come into contact with food is dictated by both the growing demands of packaging manufacturers, as well as new food products resulting from the needs of consumers.

The packaging industry is one of the most dynamically developing sectors of the today's economy. The most common factors that encourage businesses to develop new packaging (by introducing packaging innovation or modifying the existing packaging solution) are [47]:

- desire to refresh the product at the maturity stage of its market life cycle;
- increasing environmental awareness and the associated external pressure to change to packaging;
- changes in product positioning: improvement of the packaging when addressing the product to a different market segment;
- responding to competition or taking action to distinguish oneself from the competition;
- strategic changes in terms of how product is display on the store shelf;
- increasing the scale of production in connection with the entry on new markets;
- achieving greater conformity of the product with other products of the company;
- introduction of qualitative changes in the product;
- introduction of technical (technological) improvements with regard to the product's packaging.

Food packaging is currently subject to dynamic change, becoming more functional and innovative and containing active substances interacting with the packaged product. A traditional, passive protective function of packaging, understood as a passive barrier to protect food from harmful external factors, has been replaced by an active protection.

Today's active packaging extends the functionality of traditional packaging with new elements. The traditional packaging maintain the shape, color, and taste of the product, protecting it from mechanical, microbiological, physical, and chemical impurities, and preventing the loss of the product ingredients, or the entering of undesirable substances from outside. They also advertise the product as a result of a suitable selection of marketing values of the packaging, such as shape, color, and typography. The traditional packaging is there to protect food and preserve its durability as long as possible, while minimizing the interaction between the packaging and the product. Active packaging, meanwhile, deliberately uses the interaction existing between the product and the packaging or the environment produced by that product. Active packaging complements the traditional packaging with new features that make it possible to optimize the conditions inside the packaging of a food product, thus significantly extending its durability. It is expected that food manufacturers will increasingly reach for active packaging so as to be able to better protect food and increase the attractiveness of their products on the one hand, and to provide a greater sense of security to their customers on the other hand [44]. In addition to protecting the very product, active packaging plays an additional role of protection against external influences. Its main functional principle is interacting with the packaged product. The concept of active packaging is based on changing the conditions inside the package, and thus to extend the life of the products. Interaction between the product and the packaging is very important and prolongs the storage period or improves the sensory properties of the product. In this type of packaging, two methods for introducing active agents are used—they are placed in small bags in the packaging or directly into the packaging material.

The selection of the right material and form of packaging for a particular food product depends on many factors. The most important among them are directly related to the physicochemical properties of the packaged item, including, e.g., chemical composition, physical condition, texture, porosity, as well as storage time and conditions under which the product will remain until consumption. Equally important is the understanding of the processes (mechanisms) and the drivers behind physical, chemical, biochemical, and biological changes that occur in the product during storage resulting in limiting its expiration date [3].

Packaging is defined as a barrier separating the product from the external environment, designed to protect the product from harmful external factors or sometimes protect the environment against the harmful effects of the product. In this sense, packaging is a barrier that does not interact with the product. Thus, taking into account that definition and consumer safety, it should be made up of materials of possibly lowest migration of the constituents to the product packaged. However, unlike the conventional packaging, active packaging is allowed to interact with the goods it covers [48]. The possibility of the emergence of such interaction poses new challenges in ensuring food safety. Some of the substances used in active materials may migrate to the food or it may occur—due to issues with the proper management of operations on the packaging line—that active elements become wrongly placed in the package. The degree of migration of the substances derived from the package and the toxicity of the migrating agent are the two main factors that determine the risk to human health. The process of determining the exposure of the hazards of the packaging material is standardized. The standards stipulate that such tests should describe the use and the intended technical result of the applications of a substance in the package, the analytical method of hazard detection, and quantification of the hazardous substance in the food and in the packaging, as well as the course of its migration. Risk characterization of a given component involves toxicological tests, the effect of this substance on human health with varying degrees of concentration, and the complete profile of the substance, including the possible products of its degradation. Substances that can migrate and affect the safety of food are, obviously, dependent on the nature of the packaging material. Since the need for food products packaging is increasing, so is consumer risk resulting from the expansion of potentially harmful substances that could migrate from the packaging to the food [49].

Using active packaging, as opposed to the traditional one, proves advantageous in many respects. The use of modern solutions in the field of packaging can contribute to a significant improvement in the sensory characteristics of food products and may ensure its microbiological safety. Its application helps to prevent food waste and enables longer transportation and storage times. It should be noted, however, that the development of new products increases the risk of the emergence of new packaging-related hazards. For this reason, active packaging is not without disadvantages, among which one should mention especially higher costs of use and excessive migration of chemicals (Table 2). In addition, improper labeling is poses a significant threat to consumer safety. The safety of active materials and products intended to come into contact with food are, therefore, regulated by law. All such products must be produced according to good manufacturing practice.

The legal regulations on active packaging

Active materials and articles may be brought to the market only if they fulfill the intended purpose of their application properly and effectively as well as they meet the requirements laid down in the legislation in this respect.

In contrast to the traditional materials and articles intended to come into contact with food, active packaging materials, and articles may change their composition and organoleptic characteristics of food provided that these changes are in line with the regulations on food and the substances released are allowed to be added to food. All changes resulting from the use of such materials and articles may not mask any signs of spoilage of food or mislead a consumer [50].

It is in the European Union that the requirements for active materials and articles intended to come into contact with food, including food packaging, are contained in the framework regulation of the European Parliament and

Table 2 Active packaging—advantages and disadvantages

Active packaging	
Disadvantages	Advantages
More expensive than the traditional packaging	Can control the internal conditions, reacting to them accordingly by emitting beneficial substances or absorbing those that negatively affect the product
Certain substances released as a result of active packaging can affect the composition of food	Detects the presence of metabolites of microorganisms, carbon dioxide, ammonia, sulfur dioxide, hydrogen sulphide, ethanol, and organic acids or amines
In the event of damage to the packaging harmful chemical reactions may occur	Allows for longer shelf life and maintaining the product intact, including sensory properties of food products
Requires more knowledge and consumer awareness	Guarantees or significantly improves the microbiological and/or microbiological safety of food
Some of the compounds used for their production (e.g., sulfur dioxide) may be deposited on the surface of fruits (e.g., grapes), and due to their strong characteristic smell, they can lead to rejection of the product by the consumer	Can reduce the use of food preservatives
Some of the chemical compounds, e.g., carbon dioxide, may help to extend the shelf life of meat, but adversely affect its color, which may have a negative impact on consumer decisions	Protects consumers against counterfeiting and tampering food products
Can be used in an unethical manner for food adulteration—using lower class raw materials or not observing and/or neglecting strict principles of good manufacturing practice	Promotes sustainable consumption
	Contributes to the protection of the environment through the use of solutions that are biodegradable and biocompatible
	Allows the consumer to make a rational and informed choice, thus increasing the trust in the product

Source: own study

Council (EC) No. 1935/2004 of 27th October 2004 on materials and articles intended to come into contact with food [51] and in the Commission Regulation (EC) No. 450/2009 of 29th May 2009 on active and intelligent materials and articles intended to come into contact with food [52].

The regulation No. 1935/2004 was introduced to ensure quality and legal certainty for application of materials, which may actively influence the behavior of food or improvement of its condition as well as of materials used for monitoring its condition. According to this regulation, active materials and articles for contact with food are designed to include ingredients, which are gradually released into food or absorb substances contained in it. The materials and articles may change the composition or the organoleptic characteristics of food only if changes are in accordance with the Community provisions applicable to food [8].

The article 3 of the framework regulation stipulates that all materials and articles intended to come into contact with food must be safe; therefore, also active packaging must be sufficiently inert to prevent transferring their constituents into food in quantities which could endanger human health, which cause unacceptable changes in the composition of the food or deterioration of the organoleptic characteristics of the food in normal and foreseeable conditions of use. While according to the article 4 of the regulation, active materials and articles may lead to changes in the composition or organoleptic characteristics of food provided that these changes are in line with the provisions on food (food additives, flavuorings, and enzymes). However, the changes must not lead to concealing signs of the initial spoilage of food through releasing or absorbing compounds such as aldehydes or amines, which could mislead a consumer. Active materials must not lead to a distortion of food condition or passing incorrect information through, for example, a change of color of food. Such practices are not permitted and contrary to the current provisions in force in this respect.

Active materials have deliberately been designed in such a way that they contain active ingredients, which may be gradually released into food or its environment or they may be absorbed from food products in accordance with the regulation (EC) No. 1935/2004. It is very important to distinguish materials, which have natural properties to absorb substances such as cellulose or to release them, e.g., wood, from the materials, which have deliberately been designed in such a way, that their components interact with the food being in contact with them. Materials such as cellulose or wood, despite the fact that they interact with food or its environment, are not considered to be active materials [53].

The detailed regulations on the use of active packaging are included in the Commission Regulation (EC) No. 450/2009 on active and intelligent materials and articles intended to come into contact with food. This act regulates issues relating to the security of application of the materials used in active packaging and defines the requirements for marketing of these materials. It also lays down the EC list of permitted substances that may be used in active components, the conditions for inclusion of substances in the list, the rules concerning marking and the obligation of having a declaration of conformity and supporting documentation [53].

As defined in the Commission Regulation (EC) No. 450/2009 "active materials and articles are those whose task it is to extend the period of the shelf life or to maintain or improve the condition of packaged food; they are deliberately designed in such a way that the ingredients contained in them release substances into the packaged food or its environment or they absorb them".

The substances included in the active ingredient used in the active material must be subjected to the safety assessment carried out by the European Food Safety Authority (European Food Safety Authority—EFSA). Since 2002, EFSA has been acting as a consultative organ to the European Commission in the field of, among others, toxicological assessment of new substances used in production of materials, and articles intended to come into contact with food. The safety assessment applies to single active substances or to combinations of substances, if a given substance interacts with another, which may lead to a strengthening of its function or the creation of new active substances.

The framework regulation of the European Parliament and the Council (EC) No. 1935/2004 of 27th October 2004 on materials and articles intended to come into contact with food as well as the Commission Regulation (EC) No. 450/2009 of 29th May 2009 on active and intelligent materials and articles intended to come into contact with food are the basis for the general requirements, safety, and marketing issues associated with active packaging. The regulation No. 1935/2004 allows for bringing active packaging for trade to the market within the European Union, while the regulation No. 450/2009 is the legal act governing the issues regarding substances or groups of substances which are an active or intelligent component [19].

Conclusion

Active packaging is an excellent solution for a wide range of applications in the food industry. Although the traditional technologies of food packaging are still widely used, the future will undoubtedly belong to the innovation represented by active packaging characteristic of the 21 century. The most important advantage resulting from their use is reduction in loss of food products due to extension of their shelf life. Active packaging should be designed in such a way that the components contained in them are released and interact with packed food. It is also possible that the components contained in packaging will absorb undesirable substances occurring inside packaging, thereby inhibiting processes leading to a deterioration of the food quality. Given the above, the argument presented in the outline, stating that active packaging constitutes a future-oriented direction of food packaging development.

Active systems are the future direction for development of food packaging and their commercial success should be expected in the coming years. It will undoubtedly result from constantly improved technologies of their production and the knowledge about mechanisms of their functioning and the effectiveness of their operation in ensuring food safety accumulated by both producers and consumers over time.

Advantages of active packaging are obvious; however, there are still issues that need to be resolved before packaging of this type will be widespread [26]. Both hazards arising from the traditional packaging as well as new materials and technology may cause deterioration of the product quality and adversely affect human health. Accordingly, there is a need for better understanding of the principles, mechanisms that govern it, and also for optimizing the use of active agents to build systems that are sufficiently effective to reduce adverse side effects and allow for accurate knowledge-based assessment of the potential hazards. There is a relatively little number of products packed in this way offered in the marked in relation to the number of solutions presented in the literature [8]. However, it is expected that these difficulties will be overcome and active packaging becomes commonly present. It is assumed that the basic research related to packaging materials, including those relating to limiting the migration of the constituents of food packaging and focused on assessing the degree of food protection, provides a starting point for further research. Numerous studies conducted on active packaging illustrate the importance of this type of packaging, especially for food products that are in retail and during their storage [54, 55].

Compliance with ethical standards

Conflict of interest The authors declared that they have no conflict of interest.

Compliance with ethics requirements This article does not contain any studies with animal or human subjects.

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